Spin Filtering in Storage Rings: Scattering within the Beam, and the FILTEX results

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Outline:

- Spin filtering & scattering within the beam: a quantum-mechanical evolution of spin-density matrix
- Why the spin-filtering on polarized electrons cancels out?
- Comparison with the kinetic equation approach of Milstein & Strakhovenko
- Interpretation of the FILTEX findings: one minor, but important, conceptual correction to Meyer's analysis
- Implications for spin-filtering of antiprotons in PAX FAIR

PAX wants polarized antiprotons at FAIR

- Tons of top class QCD: FAIR as a unique successor of DIS physics
- Get polarized antiprotons uniquely by spin filtering: need a scrutiny of the FILTEX result
- The textbook optics: optical polarizer absorbs the "wrong" polarization.
- Spin filtering of neutrons in polarized He^3 - a popular source of polarized neutrons.
- Internal atomic polarized $H\uparrow$ and $D\uparrow$ cell targets - a unique choice for a polarizer.
- Polarized atom↑ = proton↑ (deuteron↑) + electron↑. Impact of electrons?
- Electron-to-proton polarization transfer (Akhiezer et al, 50's).: QED, is routinely used at MAMI, Bates, Jlab for G_E/G_M
- H.O.Meyer's question: what scattering within the beam does to filtering?

The transmission and scattering

- Why is the sky that blue? It is exclusively the scattered light!
- Why is the setting sun so reddish? It is exclusively the transmitted light!
- Why the sun changes its color? Transmission changes the unscattered light!
- Optical filtering: with rare exceptions one only deals with the transmitted light.
- Unique feature of storage rings: a mixing of the transmitted and scattered beam
- The technical description by the polarization dependent refraction index

$$n = 1 + \frac{2\pi}{p^2} N \hat{f}(o)$$

- The forward NN scattering amplitude $\hat{f}(o)$ depends on the beam and target spins
- Polarized target is an optically active medium!

The kinematics of p-atom scattering in storage ring

- Screening of $e\&p$ Coulomb fields beyond the Bohr radius a_B: incoherent quasielastic (E) scattering off protons and electrons at

$$\theta \gtrsim \theta_{min} = \frac{\alpha_{em} m_e}{\sqrt{2m_p T_p}} \Longrightarrow d\sigma_E = d\sigma_{el}^p + d\sigma_{el}^e$$

- Light electron do not to deflect heavy protons (Horowitz& Meyer): $\theta \leq \theta_e = m_e/m_p$
- Dominant Coulomb pp scattering up to

$$\theta \lesssim \theta_{Coulomb} \approx \sqrt{2\pi\alpha_{em}/m_p T_p \sigma_{tot,nucl}^{pp}} \approx 100\text{mrad}$$

- FILTEX ring acceptance $\theta_{acc} = 4.4$ mrad.
- Strong inequality $\theta_{min} \ll \theta_e \ll \theta_{acc} \ll \theta_{Coulomb}$
- The corollaries: (i) pe scattering entirely within the stored beam, (ii) Beam losses dominated by Coulomb pp scattering.

Do we care about electrons in the hydrogen target?

- Beam attenuation: $\hat{\sigma}_{tot}(p - atom) \equiv \hat{\sigma}^{pp}_{tot} + +\hat{\sigma}^{pe}_{tot}$.
- The pe X-section is gigantic:

$$\hat{\sigma}^{pe}_{tot} = \hat{\sigma}^{e}_{el}(> \theta_{\min}) \approx 4\pi\alpha^2_{em}a^2_B \approx 2 \cdot 10^4 Barn$$

How do we extract $\sigma^{pp}_{tot,nucl} \sim 40$ mb on top of such a background?

- $\theta \leq \theta_e \ll$ angular divergence of any beam, pe scattering is entirely within the beam and does not cause any attenuation!
- Skrinsky's question (2004, unpublished): shall the spin filtering by $e\uparrow$ be observable?
- Milstein & Strakhovenko (2005): electrons wouldn't work! (independent & simultaneous observation by NNN & F.Pavlov within a very different formalism).
- Getting rid of Coulomb pp scattering in $\sigma^{pp}_{tot,nucl}$:
  (i) measure transmitted beam intensity with acceptance $> \theta_{Coulomb}$,
  (ii) extrapolate to zero acceptance angle.

Transmission vs. Scattering within the Ring

- Polarization of the transmitted beam: propagates at ZERO scattering angle, gets polarized by absorption & elastic scattering out of the beam
- Lost & found polarization of scattered particles.
- Pertinent features of spin filtering in storage rings (the poor theorists notion):
  (i) ultra-thin target,
  (ii) $\theta \geq \theta_{acc}$: scattering out of the beam pipe,
  (iii) ring optics (betatron oscillations & focusing & defocusing & electron cooling & ...): transverse momentum $\boldsymbol{p}$ gets randomized between consecutive interactions with the target,
  (iv) angular divergence of the beam at the target $\ll \theta_{acc}$.
- The appropriate quantum-mechanical approach: the evolution equation for the spin-density matrix of the stored beam

The In-Medium Evolution of Transmitted Beam

- Time = distance z traversed in the medium.

$$\text{Fermi} \quad \text{Hamiltonian} = \hat{H} = \frac{1}{2} N \hat{F}(0) = \frac{1}{2} N [\hat{R}(0) + i \hat{\sigma}_{tot}]$$

$N =$ density of atoms in the target.

- The density matrix of the stored beam

$$\hat{\rho}(\boldsymbol{p}) = \frac{1}{2} [I_0(\boldsymbol{p}) + \sigma \boldsymbol{s}(\boldsymbol{p})]$$

- Textbook quantum-mechanical evolution for pure transmission ($\theta_{acc} \to 0$)

$$\frac{d}{dz} \hat{\rho}(\boldsymbol{p}) = i[\hat{H}, \hat{\rho}(\boldsymbol{p})] = \underbrace{i \frac{1}{2} N \Big(\hat{R} \hat{\rho}(\boldsymbol{p}) - \hat{\rho}(\boldsymbol{p}) \hat{R} \Big)}_{\text{Real potential=Pure refraction}} - \underbrace{\frac{1}{2} N \Big(\hat{\sigma}_{tot} \hat{\rho}(\boldsymbol{p}) + \hat{\rho}(\boldsymbol{p}) \hat{\sigma}_{tot} \Big)}_{\text{(Imaginary potential=Pure attenuation)}}$$

Evolution of Transmitted Beam Cont'd

- Spin dependence:

$$\hat{\sigma}_{tot} = \sigma_0 + \underbrace{\sigma_1(\sigma \cdot Q) + \sigma_2(\sigma \cdot \boldsymbol{k})(Q \cdot \boldsymbol{k})}_{spin-sensitive\ loss},$$

$$\hat{R} = R_0 + \underbrace{R_1(\sigma \cdot Q) + R_2(\sigma \cdot \boldsymbol{k})(Q \cdot \boldsymbol{k})}_{\sigma \cdot \text{Pseudomagnetic field}}$$

$\boldsymbol{k}$ = beam axis, Q = target polarization.

- Evolution of the beam polarization $P = \boldsymbol{s}/I_0$

$$dP/dz = \underbrace{-N\sigma_1(Q - (P \cdot Q)P) - N\sigma_2(Q\boldsymbol{k})(\boldsymbol{k} - (P \cdot \boldsymbol{k})P)}_{\text{(Polarization buildup by spin-sensitive loss)}}$$

$$+ \underbrace{NR_1(P \times Q) + nR_2(Q\boldsymbol{k})(P \times \boldsymbol{k})}_{\text{(Spin precession in pseudomagnetic field)}}$$

- Precession is missed in Milstein-Strakhovenko kinetic equation.
- Still equivalence to the evolution of the density matrix upon averaging over precessions.

The polarization buildup

- Coupled evolution equations fot pure transmission

$$\frac{d}{dz}\begin{pmatrix} I_0 \\ s \end{pmatrix} = -N \begin{pmatrix} \sigma_0(>\theta_{\rm min}) & Q\sigma_1(>\theta_{\rm min}) \\ Q\sigma_1(>\theta_{\rm min}) & \sigma_0(>\theta_{\rm acc}) \end{pmatrix} \cdot \begin{pmatrix} I_0 \\ s \end{pmatrix},$$

- Solutions

$$\propto \exp(-\lambda_{1,2} N z)$$

with eigenvalues

$$\lambda_{1,2} = \sigma_0 \pm Q\sigma_1$$

- Reduction to Meyer's equation for pure transverse polarizations:

$$\frac{dP}{dz} = -N\sigma_1 Q(1 - P^2)$$

$$P(z) = -\tanh(Q\sigma_1 N z)$$

- Any spin-dependent loss filters spin of the stored beam.

Scattering within the and Spin Filtering

- Quasielastic (E) $p + atom \to p'_{scatt} + e + p_{recoil}$, $\boldsymbol{q} =$ momentum transfer:

$$\frac{d\hat{\sigma}_E}{d^2\boldsymbol{q}} = \frac{1}{(4\pi)^2}\hat{\mathfrak{F}}(\boldsymbol{q})\hat{\rho}\hat{\mathfrak{F}}^\dagger(\boldsymbol{q}) = \frac{1}{(4\pi)^2}\hat{\mathfrak{F}}_e(\boldsymbol{q})\hat{\rho}\hat{\mathfrak{F}}_e{}^\dagger(\boldsymbol{q}) + \frac{1}{(4\pi)^2}\hat{\mathfrak{F}}_p(\boldsymbol{q})\hat{\rho}\hat{\mathfrak{F}}_p{}^\dagger(\boldsymbol{q})$$

- Lost and found: scattering within the beam at $\theta \leq \theta_{acc}$
- Formal derivation from multiple-scattering theory: unitarity (loss-recovery balance) is satisfied rigorously.

$$\begin{aligned}
\frac{d}{dz}\hat{\rho} = i[\hat{H},\hat{\rho}] \quad &= \quad \underbrace{i\frac{1}{2}N\Big(\hat{R}\hat{\rho}(\boldsymbol{p}) - \hat{\rho}(\boldsymbol{p})\hat{R}\Big)}_{Ignore\ this\ precession} \\
&- \quad \underbrace{\frac{1}{2}N\Big(\hat{\sigma}_{tot}\hat{\rho}(\boldsymbol{p}) + \hat{\rho}(\boldsymbol{p})\hat{\sigma}_{tot}\Big)}_{Evolution\ by\ loss} \\
&+ \quad \underbrace{N\int^{\Omega_{acc}}\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}(\boldsymbol{q})\hat{\rho}(\boldsymbol{p}-\boldsymbol{q})\hat{\mathfrak{F}}^\dagger(\boldsymbol{q})}_{\text{Lost and found: scattering within the beam}}
\end{aligned}$$

Needle-Sharp Scattering off Electrons: $\theta_e \ll \theta_{acc}$

- Pure into-the-beam scattering
- Breit pe interaction (1929): Coulomb + hyperfine + tensor + negligible spin-orbit

$$U(\boldsymbol{q}) = \alpha_{em}\left\{\frac{1}{\boldsymbol{q}^2} + \mu_p \frac{(\sigma_p \boldsymbol{q})(\sigma_e \boldsymbol{q}) - (\sigma_p \sigma_e \boldsymbol{q}^2}{4 m_p m_e \boldsymbol{q}^2}\right\}$$

$$\hat{\sigma}^e_{tot} = \underbrace{\sigma^e_0}_{Coulomb} + \underbrace{\sigma^e_1(\sigma_p \cdot Q_e) + \sigma^e_2(\sigma_p \cdot \boldsymbol{k})(Q_e \cdot \boldsymbol{k})}_{Coluomb\times(Hyperfine+Tensor)}$$

- Horowitz-Meyer (1994): substantial transfer of polarization to scattered protons!
- Polarization of scattered protons P_f (transverse case):

$$\sigma^e_0 P_f = \sigma^e_0 P + \sigma^e_1 Q_e$$

- clearcut electron-to-proton spin transfer (Akhiezer,...,Horowitz-Meyer)
- absolutely negligible spin-flip (Milstein-Strakhovenko)

Skrinsky: do electrons polarize (anti)protons?

- Electron contribution to the tranmission

$$\frac{1}{2}\frac{d}{dz}I_0(\boldsymbol{p})(1+\sigma\cdot P(\boldsymbol{p})) = -\frac{1}{2}NI_0(\boldsymbol{p})\Big[\underbrace{\sigma_0^e+\sigma_1^e PQ_e}_{particle\ number\ loss} + \sigma\underbrace{\left(\sigma_0^e P+\sigma_1^e Q_e\right)}_{selective\ spin\ loss}\Big]$$

- Lost & found (precession-averaged) from scattering within the beam :

$$\begin{aligned} & N\int\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}_e(\boldsymbol{q})\hat{\rho}(\boldsymbol{p}-\boldsymbol{q})\hat{\mathfrak{F}}_e^\dagger(\boldsymbol{q}) \\ = & \frac{1}{2}NI_0(\boldsymbol{p})\int\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}_e(\boldsymbol{q})\hat{\mathfrak{F}}_e^\dagger(\boldsymbol{q}) + \frac{1}{2}Ns(\boldsymbol{p})\int\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}_e(\boldsymbol{q})\sigma\hat{\mathfrak{F}}_e^\dagger(\boldsymbol{q}) \\ = & \underbrace{\frac{1}{2}NI_0(\boldsymbol{p})\left[\sigma_0^e+\sigma_1^e(P\cdot Q)\right]}_{Lost\&found\ particle\ number} + \underbrace{\frac{1}{2}NI_0(\boldsymbol{p})\sigma\left[\sigma_0^e P+\sigma_1^e Q_e\right]}_{Lost\&found\ spin} \end{aligned}$$

- $\hat{\sigma}_{tot} \equiv \hat{\sigma}^p_{abs} + \hat{\sigma}^p_{el}(>\theta_{\min}) + \hat{\sigma}^e_{el}(>\theta_{\min}) \Longrightarrow \hat{\sigma}_{tot} - \hat{\sigma}^e_{el}(>\theta_{\min}) = \hat{\sigma}^p_{abs} + \hat{\sigma}^p_{el}(>\theta_{\min})$.
- Skrinsky' concern was well taken: electrons in the target are invisible!

Nuclear *pp* Scattering within the Beam

Decompose pure transmission losses (transverse polarization)

$$\frac{d}{dz}\hat{\rho} = -\underbrace{\frac{1}{2}N\Big(\hat{\sigma}_{tot}(>\theta_{\rm acc})\hat{\rho}(\boldsymbol{p}) + \hat{\rho}(\boldsymbol{p})\hat{\sigma}_{tot}(>\theta_{\rm acc})\Big)}_{Unrecoverable\ transmission\ loss}$$

$$-\ \frac{1}{2}NI_0(\boldsymbol{p})\Big[\underbrace{\sigma_0^{el}(<\theta_{\rm acc}) + \sigma_1^{el}(<\theta_{\rm acc})PQ}_{Potentially\ recoverable\ particle\ loss} + \sigma\underbrace{\Big(\sigma_0^{el}(<\theta_{\rm acc})P + \sigma_1^{el}(<\theta_{\rm acc})Q\Big)}_{Potentially\ recoverable\ spin\ loss}\Big]$$

Angular divergence of the beam at target $\ll \theta_{acc}$: integrate over $\boldsymbol{p}$

$$\int d^2\boldsymbol{p}\int^{\Omega_{\rm acc}}\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}(\boldsymbol{q})\hat{\rho}(\boldsymbol{p}-\boldsymbol{q})\hat{\mathfrak{F}}^\dagger(\boldsymbol{q}) =$$

$$\left[\int d^2\boldsymbol{p}I_0(\boldsymbol{p})\right]\cdot\int^{\Omega_{\rm acc}}\frac{d^2\boldsymbol{q}}{(4\pi)^2}\hat{\mathfrak{F}}(\boldsymbol{q})\frac{1}{2}\Big(1+\sigma P\Big)\hat{\rho}(\boldsymbol{q})\hat{\mathfrak{F}}^\dagger(\boldsymbol{q}) = \hat{\sigma}^E(\le\theta_{\rm acc})\cdot\int d^2\boldsymbol{p}I_0(\boldsymbol{p})$$

The mismatch of the loss and recovery

$$\Delta\hat{\sigma} = \frac{1}{4}\Big(\hat{\sigma}_{el}(<\theta_{\rm acc})(1+\sigma P) + (1+\sigma P)\hat{\sigma}_{el}(<\theta_{\rm acc})\Big) - \hat{\sigma}^E(\le\theta_{\rm acc})$$

Precession averaged scattering within the ring

$$\hat{\sigma}^E(\leq \theta_{\rm acc}) = \underbrace{\sigma_0^{el}(\leq \theta_{\rm acc}) + \sigma_1^{el}(\leq \theta_{\rm acc})(P \cdot Q)}_{Lost\ \&\ found\ particles}$$

$$+ \underbrace{\sigma \cdot \left(\sigma_0^E(\leq \theta_{\rm acc})P) + \sigma_1^E(\leq \theta_{\rm acc})Q)\right)}_{Lost\ \&\ found\ spin}$$

The mismatch X-section operator

$$\Delta\hat{\sigma} = \underbrace{\sigma_0^{el}(< \theta_{\rm acc}) + \sigma_1^{el}(< \theta_{\rm acc})PQ_e}_{Potentially\ recoverable\ particle\ loss} + \underbrace{\sigma\left(\sigma_0^{el}(< \theta_{\rm acc})P + \sigma_1^{el}(< \theta_{\rm acc})Q_e\right)}_{Potentially\ recoverable\ spin\ loss}$$

$$- \underbrace{\sigma_0^{el}(\leq \theta_{\rm acc}) + \sigma_1^{el}(\leq \theta_{\rm acc})(P \cdot Q)}_{Lost\ \&\ found\ particles} - \underbrace{\sigma \cdot \left(\sigma_0^E(\leq \theta_{\rm acc})P + \sigma_1^E(\leq \theta_{\rm acc})Q\right)}_{Lost\ \&\ found\ spin}$$

$$= \sigma\left(2\Delta\sigma_0 P + \Delta\sigma_1 Q\right)$$

Mismatch cont'd

- $\Delta\sigma_{0,1}$: a mismatch between the spin of the beam taken away by the scattered particle and the lost & found spin put back by after the particle scatters within the beam (spin-flip=

$$
\begin{aligned}
\sigma_1^{el}(>\theta_{\rm acc}) &= \frac{1}{2}\int_{\theta_{\rm acc}} d\Omega\Big(d\sigma/d\Omega\Big)\Big(A_{00nn}+A_{00ss}\Big)\\
\Delta\sigma_0 &= \frac{1}{2}[\sigma_0^{el}(\le\theta_{\rm acc})-\sigma_0^{E}(\le\theta_{\rm acc})]\\
&= \frac{1}{2}\int_{\theta_{\rm min}}^{\theta_{\rm acc}} d\Omega\frac{d\sigma}{d\Omega}\Big(1-\frac{1}{2}D_{n0n0}-\frac{1}{2}D_{s'0s0}\cos(\theta_{lab})\Big)\\
\Delta\sigma_1 &= \sigma_1^{el}(\le\theta_{\rm acc})-\sigma_1^{E}(\le\theta_{\rm acc})\\
&= \frac{1}{2}\int_{\theta_{\rm min}}^{\theta_{\rm acc}} d\Omega\frac{d\sigma}{d\Omega}\Big(A_{00nn}+A_{00ss}-K_{n00n}-K_{s'00s}\cos(\theta_{lab})\Big)
\end{aligned}
$$

- The SAID menagerie:
  $A_{00nn}=A_{yy}$, $A_{00ss}=A_{xx}$, $K_{n00n}=D_t$, $D_{s'0s0}=R$, $D_{n0n0}=D$, $K_{s'00s}=-R'_t$.
- Milstein & Strakhovenko relate $\Delta\sigma_{0,1}$ to spin-flip scattering.

Polarization Buildup

- Coupled evolution equations after into-the-beam scattering

$$\frac{d}{dz}\begin{pmatrix} I_0 \\ s \end{pmatrix} = -n\begin{pmatrix} \sigma_0(>\theta_{\rm acc}) & Q\sigma_1(>\theta_{\rm acc}) \\ Q(\sigma_1(>\theta_{\rm acc})+\Delta\sigma_1) & \sigma_0(>\theta_{\rm acc})+2\Delta\sigma_0 \end{pmatrix}\cdot\begin{pmatrix} I_0 \\ s \end{pmatrix},$$

- Solutions $\propto \exp(-\lambda_{1,2}Nz)$ with eigenvalues

$$\lambda_{1,2} = \sigma_0 + \Delta\sigma_0 \pm \sigma_3, \quad Q\sigma_3 = \sqrt{Q^2\sigma_1(\sigma_1+\Delta\sigma_1)+\Delta\sigma_0{}^2},$$

- The polarization buildup (also Milstein&Strakhovenko)

$$P(z) = -\frac{Q(\sigma_1+\Delta\sigma_1)\tanh(Q\sigma_3 Nz)}{Q\sigma_3+\Delta\sigma_0\tanh(Q\sigma_3 Nz)}$$

- The effective small-time polarization cross section

$$\sigma_P \approx -Q(\sigma_1+\Delta\sigma_1)$$

Spin Deep under the Coulomb peak

- Pure nuclear scattering into $\theta \leq \theta_{acc} = 4.4 \cdot 10^{-3}$ is entirely negligible.
- "Abnormal" $\theta_{acc} \ll \theta_{Coulomb}$: deep under the Coulomb peak, entirely inaccessible in scattering experiments, important for storage rings. Need extrapolations of hadronic amplitudes.
- Pauli principle $\Longrightarrow$ double-spin dependence from exchange interaction

$$
\begin{aligned}
\hat{\mathcal{F}}_{Coulomb} &= \frac{1}{2}\mathcal{F}(\theta) + \frac{1}{4}(1 + \sigma_1 \cdot \sigma_2)\mathcal{F}(\pi - \theta) \\
&= \underbrace{\mathcal{F}_0(\theta)}_{Coulomb\ singularity\ 1/\theta^2} + \underbrace{\mathcal{F}_1(\theta)}_{Constant}\ \sigma_1 \cdot \sigma_2
\end{aligned}
$$

- Add Breit and nuclear spin-spin interactions $\star$ $1/\theta^2$ enhancement makes interference $\propto \mathcal{F}_0(\theta)\mathcal{F}_1(\theta)$ substantial.
- Upon azimuthal integrations spin-flips don't interfere with the dominant $\mathcal{F}_0(\theta)$: negligible small $\Delta\sigma_{0,1}$

FILTEX according to Meyer-Horowitz:

- The FILTEX as published in 1993: $\sigma_P = 63 \pm 3(stat.)$ mb, a 20σ measurement!
- Better understanding of target density & polarization (F.Rathmann, PhD):
  $\sigma_P = 72.5 \pm 5.8(stat. + sys.)$ (stat.)
- The expectation from filtering by pure nuclear scattering: $\sigma_{P,expected} = 122$ mb.
- H.O. Meyer: correct σ_P for scattering within the beam. Strong CNI, Meyer's reevaluation $\sigma_1(> \theta_{\rm acc}) = 83$ mb (SAID of 94) instead of 122 mb
- Add scattering within the beam off polarized electrons: $\delta\sigma_1^{ep} = -70$ mb
- Add scattering within the beam off polarized protons: $\delta\sigma_1^{ep} = +52$ mb
- Net result: $\sigma_P = 65$ mb. Good but accidental agreement with FILTEX!
- What went wrong: : Double counting, Meyer should have started with loss from $\theta > \theta_{min}$, and then add scattering within the beam. Still, Meyer asked right questions and was infinitesimally close to the correct answer!

FILTEX and scattering within the ring

- NNN-Pavlov: SAID-SP05 for filtering by loss: $\sigma_1(>\theta_{\text{acc}}) = -85.6$ (only marginal changes from SAID to Nijmegen databases).
- Spin deep under the Coulomb peak:

$$\hat{\mathfrak{F}} = \underbrace{\mathfrak{F}_0(\theta)}_{Coulomb \propto 1/\theta^2} + \underbrace{\mathfrak{F}_1(\theta)}_{Breit+Nuclear} \sigma_1 \cdot \sigma_2 + (\text{other two} - \text{spin terms})$$

- Treatment is identical to that of the Breit proton-electron interaction.
- Careful extrapolations under the Coulomb peak
- Scattering within the beam cancels filtering by transmission losses:

$$\hat{\sigma}_{tot} \equiv \hat{\sigma}^p_{abs} + \hat{\sigma}^p_{el}(>\theta_{\text{min}}) \Longrightarrow \hat{\sigma}_{tot} - \hat{\sigma}^p_{el}(\theta_{\text{min}} \leq \theta \leq \theta_{\text{acc}}) = \hat{\sigma}^p_{abs} + \hat{\sigma}^p_{el}(>\theta_{\text{acc}}).$$

- Nonrelativistic heavy particles love retaining their spin: very small mismatch X-section

$$\Delta\sigma_1 \approx -6 \cdot 10^{-3}\ \text{mb}$$

- Full agreement with Milstein & Strakhovenko result in terms of the spin-flip X-section.

Conclusions: what is the future for PAX?

- FILTEX: an important proof of the principle of spin filtering.
- A consensus between theorists (Budker Institute & IKP FZJ): Polarized electrons in polarized atoms wouldn't polarize antiprotons in storage rings.
- H.O. Meyer: scattering within the beam + CNI reduce the expected $\sigma_P = 122$ mb down to $\sigma_P = 85.6$ mb (SAID-SP05).
- Still slight disagreement between experiment $\sigma_P = 72.5 \pm 5.8 (stat. + sys.)$ (FILTEX) and theory, $\sigma_P = 85.6 mb$ (Meyer & Budker Institute & IKP FZJ).
- Solution for PAX: spin filtering by nuclear antiproton-proton interaction . Must be optimized with existing antiprotons.
- $N\bar{N}$ models are encouraging, but unreliable.
- Meyer-Horowitz vs. Budker-Juelich: hydrogen and deuterium targets with longitudinaly polarized beams at COSY.